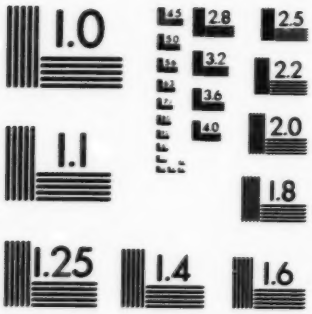
MS109

Micromedia Limited



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

This statement was filmed with this document.
If the pages of the document are less clear
than this statement it is due to the poor
photographic quality of the document.

NATIONAL MICROGRAPHICS ASSOCIATION

24x

Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

EXAMINATION OF A CORRODED METAL CHIMNEY

J.B. GILMOUR & R. POIRIER
CORROSION SCIENCE SECTION

OCTOBER, 1983

This document is an unedited interim report prepared primarily for discussion and internal reporting purposes. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non-révisé et rédigé principalement pour fin de discussion et de documentation interne. Il ne représente nullement l'expression officielle de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

MINERALS RESEARCH PROGRAM

20 pp

PHYSICAL METALLURGY RESEARCH LABORATORIES
REPORT: MRP/PMRL 83-66(TR)

MICROMEDIA
SEP 24 1984

84- 4727

PHYSICAL METALLURGY RESEARCH LABORATORIES
REPORT MRP/PMRL 83-66(TR)

EXAMINATION OF A CORRODED METAL CHIMNEY

by

J.B. Gilmour* and R. Poirier**

ABSTRACT

Sections of a corroded prefabricated metal chimney were examined in the laboratory in an attempt to determine the cause of corrosion.

It was concluded that moisture in the insulation was responsible for the corrosion of the outer prepainted galvanized steel casing and that condensation of flue gases had resulted in both pitting and general corrosion of the 430 stainless steel liner.

---

*Head, Corrosion Science Section, **Technician, Corrosion Science Section, Physical Metallurgy Research Laboratories, Minerals Research Program, CANMET, Ottawa, Energy, Mines and Resources, Canada.

LABORATOIRES DE LA MÉTALLURGIE PHYSIQUE
RAPPORT N° MRP/PMRL 83-66(TR)

EXAMEN D'UNE CHEMINÉE MÉTALLIQUE CORRODÉE

par

J.B. Gilmour* et R. Poirier**

RÉSUMÉ

Des sections d'une cheminée métallique préfabriquée corrodée ont été examinées en laboratoire afin de déterminer la cause de la corrosion.

Il a été conclu que de l'humidité accumulé dans la matière isolante a causé la corrosion de l'enveloppe extérieure en acier galvanisé prépeint et que la condensation des gaz de fumée avait entraîné les piqûres et la corrosion générale de la doublure en acier in oxydable 430.

---

*Chef, Section des sciences de la corrosion, **Technicien, Section des sciences de la corrosion, Laboratoires de la métallurgie physique, Programme de recherche sur les minéraux, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

INTRODUCTION

The Corrosion Science Section of PMRL was consulted by A.C.S. Hayden of the Energy Research Laboratories (ERL) of CANMET about the reasons for the corrosion of a prefabricated Class A metal chimney. Hayden had obtained one section (section C Fig. 1) of a chimney which showed extensive corrosion of the outer casing and perforation of the liner. Because of the advanced state of corrosion of this section, it was recommended that additional sections from the same chimney be obtained because examination of a section in earlier stages of corrosion might indicate the sequence of events leading to failure. Subsequently, two additional sections were obtained (Fig. 1).

The sections received were from a chimney from a house in Fredricton, New Brunswick where the chimney had been used for a total of four heating seasons. The section originally received had been used for the four seasons and the two sections received subsequently for only two seasons. Details of the installation will be found in Appendix A where the sections received are labelled C, D, and F. The chimney had been used with a wood-burning stove. As far as can be determined, no coal was ever burned in the stove and no creosote-reducing additives were used.

EXAMINATION OF THE SECTIONS

Of the three sections of chimney received, only one was examined in detail (referred to as section D although, because the sections were not marked, it was impossible to distinguish between them). However, as the first section received by ERL (section C) showed such extensive corrosion it will be described here. The section that was examined in detail will then be described.

There is no reason to believe that the different sections examined were not all identical when manufactured. These sections consist of a 0.43-mm thick Type 304 stainless steel upper (male) fitting, a 0.32-mm thick Type 430 stainless steel inner liner, a 0.43-mm thick Type 430 bottom (female) fitting and a 0.45-mm thick prepainted galvanized steel outer casing. (Identification of the alloys was confirmed by electron-probe microanalysis of samples from section D). Figure 2 is a drawing showing some of the details of construction. The insulating material was not examined in detail but when viewed with

a low power stereomicroscope appeared to consist of a mixture of short fibres (glass or mineral wool) and a fine powdered material.

The insulation in sections D and E obtained subsequent to the receipt of the extensively corroded section C was found to be saturated with water. (When the sections were stood on end for photographing, water seeped out of the end fitting). It is probable that much of this water entered the chimney sections during storage outdoors after they had been removed from the house. However, discussions with the occupant of the house indicated that the insulation in some of the sections (E and G, replaced after one year) may have been wet when in use. These sections were noticeably warmer than the other sections when the stove was in use, probably indicating that the insulation was wet (and therefore had low insulating properties). The sections were replaced when rust staining became visible on the outside of the casing.

Although the sections are designed to minimize the entry of rain water into the insulation when correctly installed, it was noted that at the top of one section the crimp joint in the casing was improperly formed and water could have entered if the section had been mounted where it was exposed to the weather. However as shown in Appendix A, this section was mounted in the living quarters of the house and thus this defect is of no consequence in this investigation. The design of the joint between the sections is such that if water gets into one section it is possible that some of the water will seep through the insulation from one section to the other. Excessive amounts of water would be expected to leak out at the joints; either into the flue or onto the exterior surface of the casing. Also, condensation on the inside of the liner should not enter the insulation but rather run down the inside (flue side) from one section to the other provided that the chimney is installed correctly: section male fittings up, as this one reportedly was.

Section C

This section was the most extensively corroded of the three received. The outer casing was heavily corroded with attack concentrated at the upper and lower ends. As shown in Fig. 1, the corrosion resulted in the disintegration of the casing in both these areas. However, in addition to the corrosion of the outer casing, the inner liner was perforated in a number of locations (Fig. 4). Close examination indicated that this corrosion originated on the inner surface of the liner (flue side). The insulation side of the liner (except where perforated) appeared to be free of corrosion.

The upper fitting on this section (304 stainless) was cracked in 19 locations around the heavily worked connection between the fitting and the casing as shown in Fig. 4. These cracks are believed to be stress corrosion cracks.

No destructive examination was made of this section.

Section D

This section was examined in detail.

Initially the top 150-mm was cut off with a hacksaw and the insulation from the top removed and stored in a plastic bag. Later the insulation was removed from the bottom and the liner removed from the casing. Various samples were cut from pieces of this section and were examined by one or more of the following procedures:

- visual
- low power stereomicroscope
- metallographic sectioning and optical metallography
- scanning electron metallography (SEM).

A sample of the insulation was dried in an oven at 105°C, weighed, exposed to 100% relative humidity at room temperature for two weeks and re-weighed. The gain in weight was about 2%.

OUTER CASING. As stated previously, the outer casing was prepainted galvanized steel. The outside of this section was in excellent condition. Some rust streaking was present but this is believed to have originated with the heavily corroded section C above it. The inside of the casing was corroded to the point that essentially all the zinc had been removed. There was no evidence that the inner surface had originally been painted and an examination of the crimped joint in the casing also indicated that the galvanized steel was painted on one side only.

Although the zinc was removed over much of the surface, the steel substrate was severely corroded only in one area near the top of the section (approximately half wall penetration). Ferrous corrosion products were found in scattered areas over much of the remainder of the casing but the intensity of attack of the steel was not great.

INNER LINER. The Type 430 inner liner showed two main forms of corrosion: 1) general corrosion and 2) pitting. Of these two forms of attack, the general corrosion was relatively minor and resulted in a dulling or etching of the original inner (flue) side of the liner. Pitting of the parts of the liner exposed to the flue gas was extensive, with thousands of small pits visible when the liner was examined under the stereomicroscope. Optical depth measurements of selected deep pits indicated that many pits in this area were over half the wall thickness deep. Figure 5 shows a deep pit in section. Figure 6 is a SEM photograph of a representative area of the liner. Many of these pits contained creosote indicating that the corrosion had taken place before the chimney was removed from service.

However, deeper pits were found on the sheltered areas of the liner where the flue gas had access to the liner but where general corrosion or etching did not take place. No creosote was found in these sheltered areas. Only two through pits were found, both near the bottom lip, but they appeared to originate from the outside of the liner. It should be noted that in this area the outside of the liner is accessible to flue gas that may penetrate between the liner and the male fitting of the section below. Although the density of pits in this sheltered area was less than on the inside of the liner, the pits were generally deeper than those on the exposed surface. Figure 7 is an SEM photograph showing a pit that perforated the liner. Figure 8 shows 4 sections from the lip on the bottom of the liner showing that pits occur from all sides of the steel in this area. Similar pits were found in the liner at the top edge where the liner was sheltered by the overlapping 304 stainless steel upper fitting of the same section.

The outer surface of the liner where it was in contact with the insulation was not corroded.

TOP FITTING. Pieces of the Type 304 stainless steel top fitting were examined with the stereomicroscope and scattered small pits were found on surfaces exposed to flue gas.

BOTTOM FITTING. Pieces of the Type 430 stainless steel bottom fitting were examined with the stereomicroscope. Pitting was found on the bottom of the fitting (non-insulation side) with a greater density of pits toward the inner (flue) edge of the fitting.

DISCUSSION

Because the sections of the chimney had been stored for a considerable length of time between their removal from use and the examination at PMRL, some uncertainty exists about the time when some of the corrosion occurred. However, as the chimney was removed from service when it was discovered that the outer casing of section C was extensively corroded, it is reasonable to assume that considerable corrosion had occurred during use and additional corrosion after removal would only have accentuated damage already existing. Moisture in the insulation would have continued to corrode the outer casing and additional moisture undoubtedly entered when the sections were stored outdoors.

The pH of the water in the liner as received at PMRL was slightly basic, 8.4, and water of this pH would not be expected to be particularly aggressive to galvanized steel. However, as two non-adjacent sections were replaced after only one year because of obvious corrosion, and as these sections had poor thermal properties (warm during operation), it seems probable that these sections contained moisture when first installed in the house. The flue temperature apparently was not high enough for a sufficiently long time to dry the insulation during operation of the stove. In addition, under certain operating conditions it may be possible for flue gas to enter the insulation through the joints between the chimney sections. If the temperature of the insulation is low, moisture in the flue gas can condense in the insulation. However, the insulation was not hydroscopic and thus, there was no direct chemical absorption of water from the flue gas.

The corrosion of the stainless steels in the chimney is an entirely different matter. As these materials were not corroded where they were in contact with the wet insulation, the moisture in the insulation was obviously not corrosive to the stainless steel.

The general corrosion of the 430 liner is most probably the result of acid-containing flue gases condensing on the inside of the liner. This type of attack is relatively minor on the section examined in detail and would not have led to failure for many years. However, section C appears to have been perforated by acid attack. The insulation in this section was probably wet (to cause the corrosion of the casing) and thus this section would have run cold, promoting condensation and acid attack. The type of acid causing

this attack is not known. However, when wood is burned, especially in a slow-burning air-tight stove, a variety of organic acids may be produced. In addition, sulphur (expected to be very low in wood) contained in the fuel will form sulphurous or sulphuric acid which will condense in a low temperature flue.

Although the acid attack of the section examined in detail was minor, pitting had perforated this section in two locations and many other pits were relatively deep.

Generally, stainless steels pit when exposed to aqueous halide (usually chloride) solutions, and elevated temperatures increase the rate and probability of attack. The aqueous phase in this instance was provided by condensation in the flue during periods of low flue temperature. Once the chimney lost its insulating properties, either through the insulation being saturated with moisture or, later in the process, by the total loss of insulation in section C, moisture from the flue gas could condense on the liner and run down the inside of the flue. However the pitting on the "sheltered" areas of the liner indicates that it was direct condensation from the flue gas that provided much of the moisture for the pitting attack.

The source of the halide ion is not so easily explained. It is presumed that the halide responsible is chloride, probably contained in the fuel burned in the stove. Typical hardwoods contain negligible chloride; however, other material burned (occasional small amounts of paper, plastics, etc.) may contain considerably more. During combustion some of the chloride may be ionized and be deposited on the liner. In addition, chlorides contained in other substances in the air of the home environment (e.g., spray can propellents) will be carried into the stove and can result in chloride in flue gas condensate. Chloride has been found in condensed flue gas from natural-gas burning furnaces and yet the fuel contained negligible chloride (1). Corrosion in combustion systems due to contamination of the air is known to occur in certain industrial and commercial operations (2). Once on the liner the chloride will contribute to pitting whenever moisture is present. Condensation in the flue occurring at times other than during the heating season would also allow this corrosion to continue.

The cracking of the upper fitting of section C appears to be the result of stress corrosion cracking. Type 304 stainless steel in hot chloride-containing solutionms is known to be susceptible to this type of attack. The

stress in this instance is the residual stress remaining after cold-forming the fitting. Again the exact source of chloride is not known but the aqueous phase must be provided by condensation in the upper part of the chimney. Once the thermal properties of this section were destroyed by the loss of the insulation, extensive condensation would be expected in the top section of this chimney. Similar stress corrosion cracks were found (but not discussed) by Brigham in the fittings of another Class A metal chimney that failed by corrosion (3).

The results of this investigation are less than satisfactory in that the exact sequence of events leading to the failure cannot be determined. It appears that some chimney sections contained moisture when installed in the house and this led to the failure of the outer casing. The original source of this moisture cannot now be determined. Condensation of flue gases caused acid attack on the liner in cold sections of the chimney. The rust streaking of the sections examined shows that, at least in later stages, moisture condensed in the upper part of the chimney and entered the insulation through holes in the liner, ran down in the insulation and seeped out of the casing at the joints between the sections. Pitting of the liner is the result of condensation in the chimney of flue gases containing chloride.

However, the main question to be asked is the more general one regarding the safety of prefabricated metal chimneys of the type examined. If this chimney had been installed in an inaccessible area (boxed in where it went through the house) the corrosion could have progressed to the point where the chimney would have been a severe fire hazard. Indeed, section C which was in the attic had reached that stage. The specific installation and mode of operation does not appear to have been non-typical and although the flue temperature was probably low much of the time, this is not unusual for chimneys used with "air-tight" wood-burning stoves. Unfortunately there does not appear to be any simple way of determining if the failure of this chimney is an isolated case, the result of some undetermined unusual factor, or is symptomatic of a widespread problem with implications for public safety.

CONCLUSIONS

The following conclusions can be drawn from this investigation:

1. The corrosion of the casing was the result of moisture in the insulation, moisture that may have been there when the chimney was installed.

2. Two forms of corrosion attacked the liner when flue gases condensed in the chimney: acid attack from flue gas and pitting after chloride had been deposited on the liner.

3. Although this chimney appears to have been operating at a low temperature for much of the time, this is not considered unusual for an "air-tight" wood-burning stove and thus it is possible that corrosion of Class A prefabricated metal chimneys may be a widespread problem.

ACKNOWLEGEMENTS

The electron probe microanalysis was performed by V. Moore of the Engineering and Metal Physics Section and the Scanning Electron Metallography by V. Chartrand of the same section.

REFERENCES

1. Hayden, A.C.S. Private communication.

2. Szilard, S. Private communication.

3. Brigham, R.J. "Investigation of the Kars chimney failure"; Division Report ERP/PMRL 81-6(CF); Declassified, CANMET, Energy, Mines and Resources, 1981 and Private communication.

Fig. 1. The three sections received by PMRL. Section C is in the centre and the section examined in detail is shown at the right. (neg 7808)

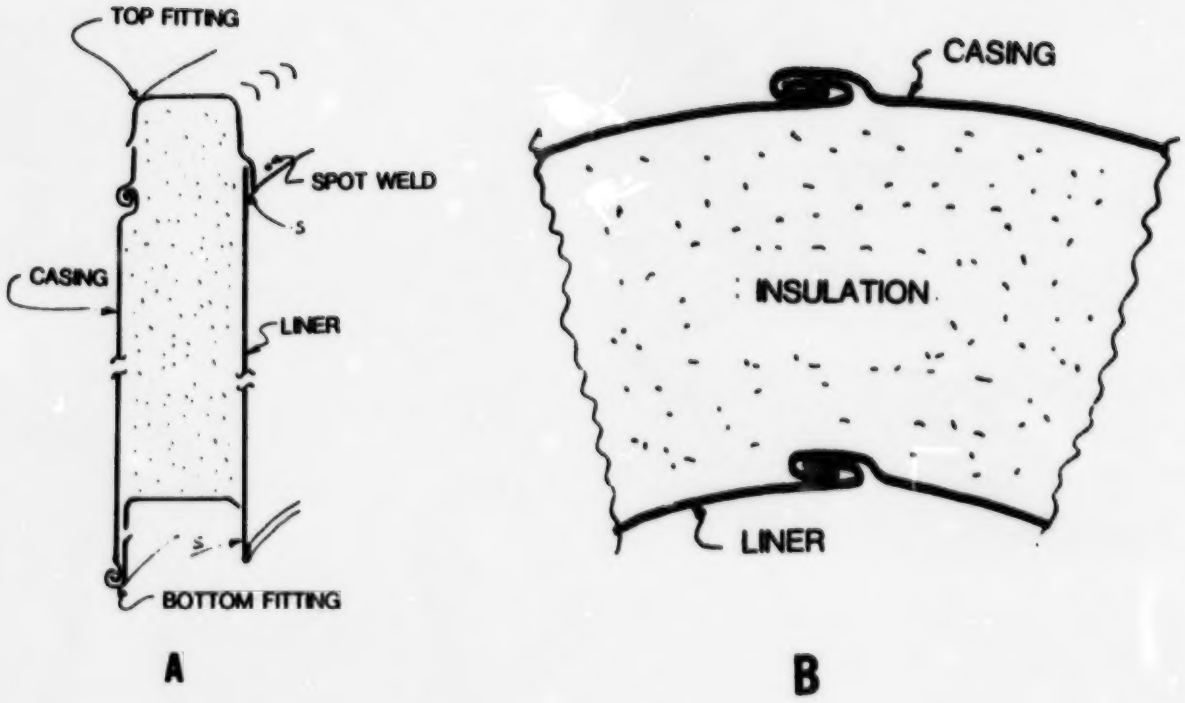


Fig. 2. Sketch showing the details of construction of the chimney sections. Not to scale. (neg 9270)

Fig. 3. Close-up photograph of the exposed liner of section C showing perforations of the liner. The stress corrosion cracks of the upper fitting are also visible. (neg 7809)

Fig. 4. Photograph showing stress corrosion cracks of the upper fitting. Nineteen such cracks were found.

Fig. 5. Metallographic section through the liner showing a deep pit. (neg 10184)

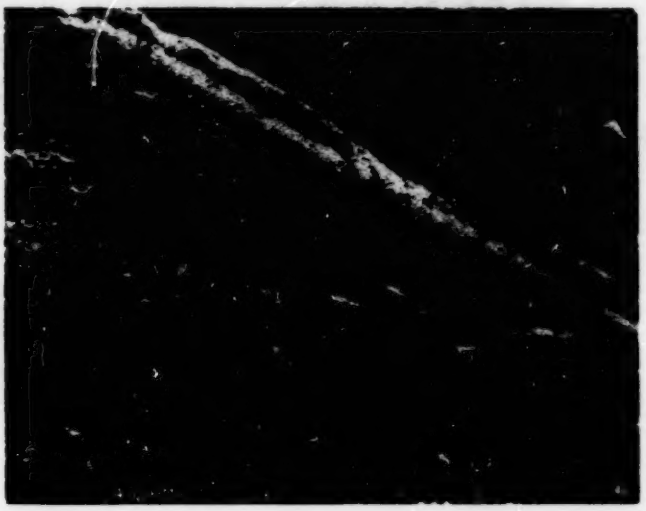
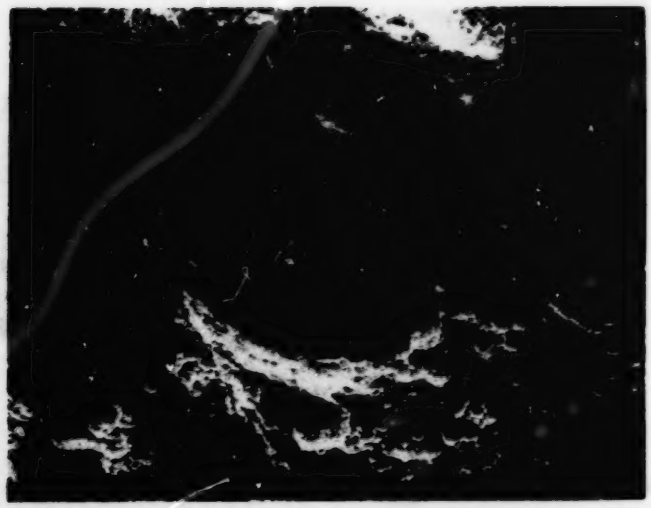
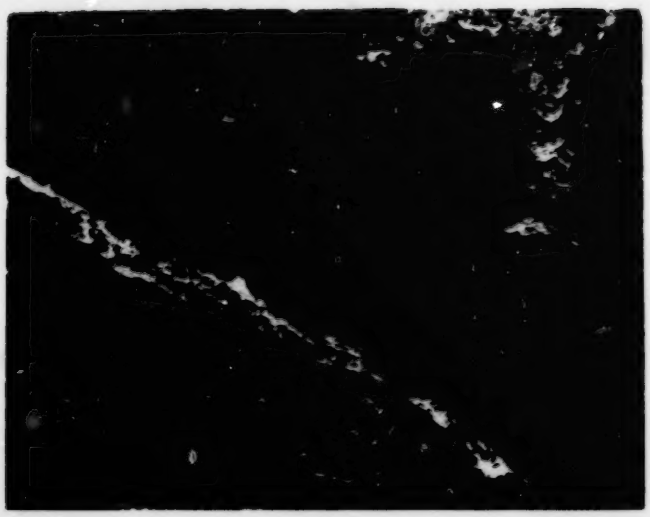


Fig. 6. Scanning electron micrograph showing many small pits on the flue side of the liner. (neg 9198)



(a) (neg 9197)



(b) (neg 9196)

Fig. 7. Scanning electron micrograph showing a perforation of the liner located just above the lip at the bottom of the liner. (a) is a view from the sheltered side of the liner, believed to be the origin side. (b) is a view from the flue side.

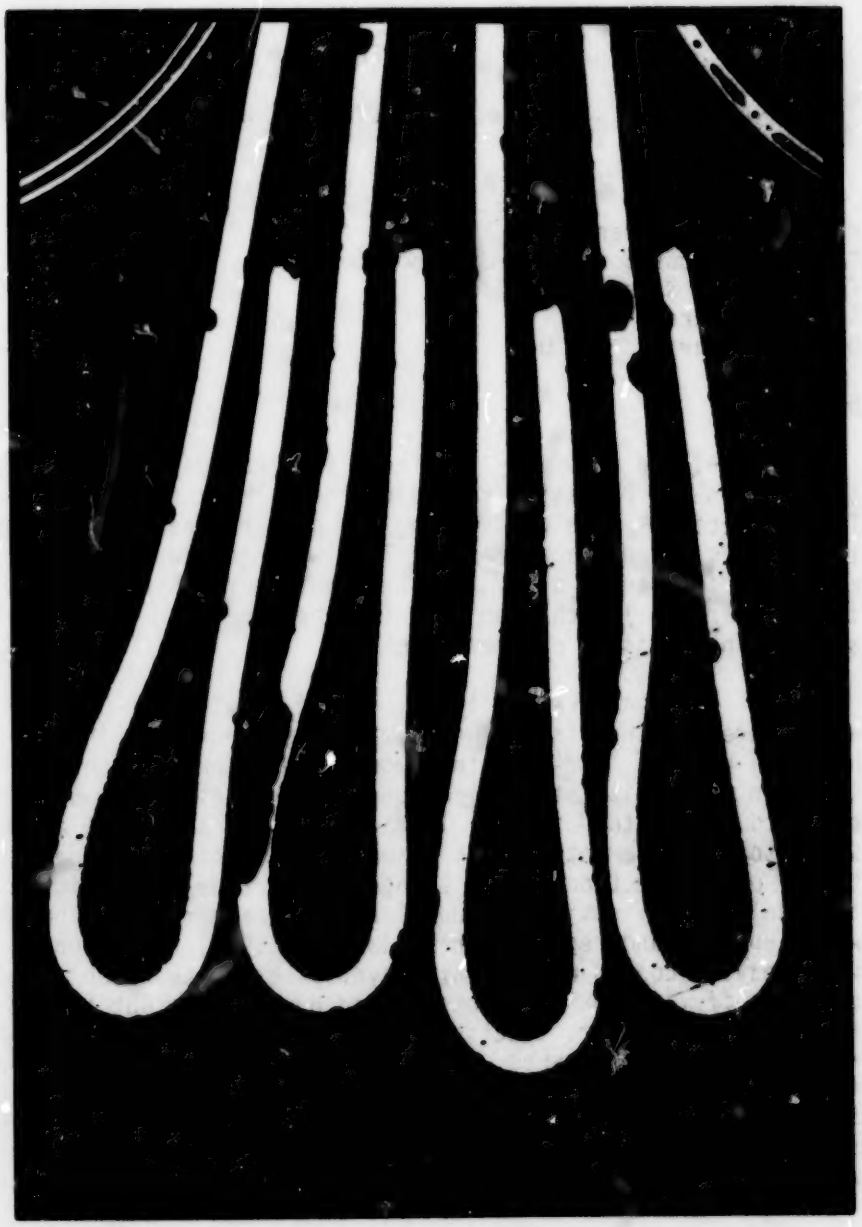


Fig. 8. Metallographic sections through the lip at the bottom of the liner. (neg 10183)

Hppendix A

ENVIRONMENT NEW BRUNSWICK | ENVIRONNEMENT NOUVEAU-BRUNSWICK

February 28, 1983

FILE NO. 8-5.21

Mr. A. C. S. Hayden
Canadian Combustion Research Laboratory
Energy Mines & Resources Canada
555 Booth Street
Ottawa, Ontario K1A 0G1

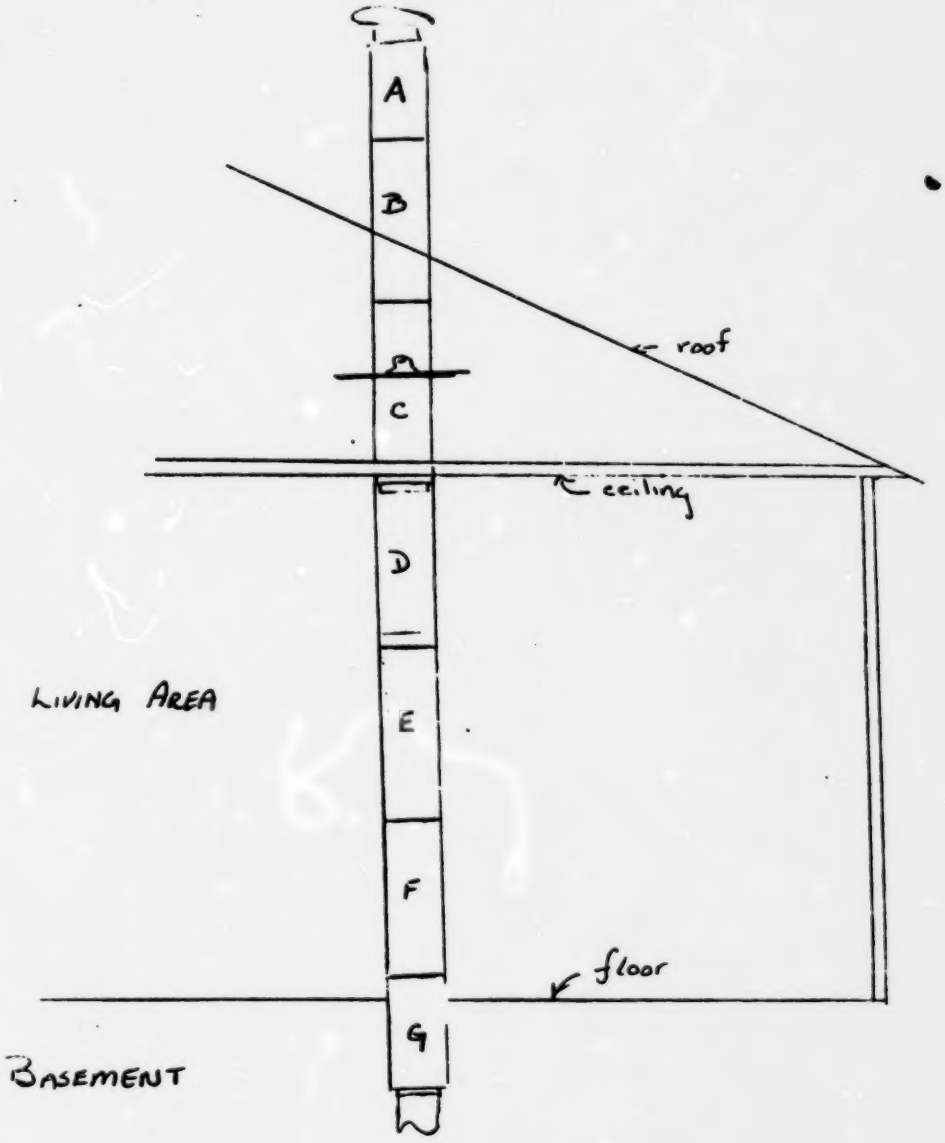
Dear Skip:

Please excuse my tardiness in sending you the further information you requested regarding the Selkirk flue I forwarded. The two sections were used during two heating seasons with about three cords burned each season. They were located in an exposed corner of the living area. Two adjacent sections failed in less than a year and I exchanged them for the type with stainless outer shell. There was no problem with them.

From the sketch, I sent "C" to you first. Sections A, B, and C were original in the house when I purchased it in 1978. They had been used in 1977-78 with a wood stove (Lakewood Cottager) on the main floor with stove pipe running vertically from the top of the stove to the bottom of "C". In March 1979, I added D-G and moved the stove to the basement with the same vertical pipe arrangement into the bottom of G. Sections E and G began to corrode almost immediately but it wasn't really noticeable until about December when I realized what was happening and replaced them (January, 1980). Sections E and G were heavily coated with a hard layer of creosote which could not be brushed off. I took them outside and burned them out before returning them to the supplier. Sections D and F had a light coating of soot which was dry and brushed off easily. I used the refurbished Selkirk for 1980-81 until I noticed the deterioration taking place in "C". The Selkirk was removed in the fall of 1981 and replaced with a brick chimney. Sections D and F were forewarded to your lab recently. They were used for two heating seasons whereas C was used for four. Sections A and B show some corrosion but not as serious as C.

Yours truly,

James F. L. Knight, P. Eng.
Chief, Air Quality Section
Pollution Control Branch



A - 18" x 7" with rain cap.
B - 30" x 7" with roof flashing
C - 30" x 7" with side support brackets
D, E, F - 30" x 7"
G 18" x 7"

SELKIRK CHIMNEY INSTALLATION

James F. L. Knight
19 Emerald St
FREDERICTON NORTH, NB